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ABSTRACT

Traditional methods of studying organizations have made useful contributions to our understanding of the relationship between formal structure and technology, but they still need to be supplemented. Comparative analysis, for example, maintains a formal, empirical tradition but is conducted at a highly aggregative level. The "constituent" approach studies the linkages among organizational components, but its findings have not been subject to much formal testing. This paper advocates an approach that facilitates detailed intra-organizational analysis while permitting the formal testing of theory. The idea is to develop a heuristic computer model that can predict an organization's structural configuration -- given knowledge of the technological interrelationships. The deviations between the actual and the predicted configurations can then be analyzed to discover ways in which the model should be revised. An initial model is constructed using the ideas of J. D. Thompson, whose bomber wing example is used as a vehicle for comparing the model's predictions to an actual structure. (Author)

ORGANIZATIONAL STRUCTURE AND TECHNOLOGY:

A COMPUTER MODEL APPROACH

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ORGANIZATIONAL STRUCTURE AND TECHNOLOGY: A COMPUTER MODEL APPROACH

A great deal of literature already exists on the effects of production or operations technology on individual and work group behavior in the organization. This particular study, however, is concerned with an area in which much controversy still persists; the way in which formal structure is affected by technological variables. For reasons which will soon become clear I shall distinguish between two current approaches to the problem; the comparative approach which takes organizations as the units of analysis and the constituent approach which utilizes organizational components as the basic units. The first seeks to establish general principles from the simultaneous study of more than one unit, but at the expense of not peering very deeply within any of them. The second is characterized by in-depth analyses of particular organizations, but at the expense of developing formal, empirically tested theory.

INTRODUCTION

At the theoretical level comparative analysis views technology as one of the most crucial (if not <u>the</u> most crucial) determinants of organizational structure (Perrow, 1967; Udy, 1965). In order to verify these claims at the empirical level the strategy has been to define and measure various dimensions of structure and technology on a sample of organizations and investigate relationships using conventional statistical techniques, e.g., Mohr (1971), Zwerman (1970), Hage and Aiken (1969), Hickson, et al (1969), Pugh et al (1969), Harvey (1968), Bell (1967), and Woodward (1965).

Undoubtedly, the most provocative study was conducted by Woodward (1965) in England who found that a measure of technological complexity was the most crucial determinant of various structural configuration characteristics such as span of control. In an American replication Zwerman (1970) corroborated

her findings. However, Pugh and his associates in a series of studies culminating in Hickson, et al (1969) found that Woodward's technological measure as well as one of their own (workflow integration) was not the primary influence on Woodward's dependent variables as well as other dimensions of structure. Hickson, et al, attributed the inconsistency to the effects of a third variable, size. Subsequently, Aldrich (1972) re-analyzed the data of Hickson, et al, using path analysis and found technology to be more crucial than the original authors thought. Meanwhile, Mohr (1971) found only weak to moderate relationships between structure (operationalized as supervisory style) and three different technology dimensions.

At this point in time the comparative approach is clearly in a state of conflict. To the extent that the causes are substantive in nature this is healthy. Our knowledge of social structure must expand as more refined theories are developed to explain the conflicts. On the other hand it appears that various methodological problems may be in part to blame. There exist differences between the above mentioned studies in defining and measuring variables (see Hickson, et al, 1969) and in sample selection (see Zwerman, 1970). Once more, probability samples are not used (see Harvey, 1968), multicollinearity often exists among independent variables (see Pugh, et al, 1969), and reliance upon cross-sectional analysis precludes the inferring of causality (see Pugh, et al, 1969). The situation for pre-1965 studies does not seem to be much better. Starbuck (1965) in reviewing some of the literature finds it difficult to draw conclusions due partially to a researcher's not ruling out systematic but unobserved variables.

There is an equally important issue which has received scant attention by the advocates of the comparative approach. Would in-depth analyses of organizations lead to added insights? Woodward to some extent realized the possibilities through her use of detailed case studies. Hickson, et al, have called for measures of technology built up machine by machine rather

than based upon an organization's predominant methods. For the most part, however, the formal study of structure and technology within the organization has not been a salient characteristic of comparative research.

As an illustration that the aggregative focus of comparative analysis can be usefully supplemented consider Blau's (1970) study of the relationships between various measures of structural differentiation and organizational size. He found that as size increases differentiation increases at a decreasing rate. Whether or not it was Blau's intent we are left with the impression that a structural configuration will expand much like the branches of a tree without ever changing its fundamental rationale. The in-depth focus of the administrative literature teaches us to be wary of this view. Business firms for example are known to switch from a functional to a divisionalized model for differentiation beyond a certain size (e.g., Chandler, 1962). The reasons are that coordination problems mount and the threat of underutilization of resources diminishes. Consequently, as the organization grows we should expect changes in the <u>nature</u> of its units and their interrelationships, as well as in the <u>number</u> of supervisory levels and units.

In the "constituent" approach emphasis is placed on how technology affects the way the organization's components are linked together. For example, Chapple and Sayles (1961) have stressed the importance of making workflow the basis for assigning activities. Their recommendations, however, are backed up only by some case examples. Lawrence and Lorsch (1967) have indicated that subunits, due to differences in environmental uncertainty including the rate of technological innovations, have different structural and behavioral characteristics, and consequently require formal mechanisms to insure integration. Their views are backed up by some rough

empirical findings on six firms in the chemical processing industry. Thompson (1967) has made a distinction between a technical core structured primarily according to technological considerations and boundary spanning units influenced mostly by the environment. In the core, technology manifests itself through three different kinds of interdependencies among basic units. Departmentalization and hierarchy follow from the effort to minimize the resulting coordination problems. Thompson has illustrated his ideas using a bomber wing of the Strategic Air Command, and Jay Galbraith (1970) has used them to investigate the product branch structure of the Boeing Company. In general, however, this second approach has not been characterized by rigorous empirical research in which conclusions are shown to stand for a wide class of organizations. In part this may be due to the difficulty in finding an appropriate methodology.

A FORMAL HEURISTIC MODEL

The research to be discussed here utilizes the second approach to gain in-depth insights, but at the same time involves a formal model capable of being tested for its generality. The model is an example of the general class of heuristic computer programs. It involves informational inputs which are transformed into decisional outputs using a set of administrative rules. The rules are embodied in a computer program which asks questions about the information and performs various calculations upon it.

Heuristic models have a well established reputation for the solution of organizational problems. Utilizing recent advances in artificial intelligence research and the psychology of human problem solving (Feigenbaum and Feldman, 1963; Newell and Simon, 1971), management scientists have written heuristic programs which select stocks for portfolios (Clarkson, 1962), schedule jobs through custom shops (Gere, 1966), allocate budgets (Gerwin,

1969), locate warehouses (Kuehn and Hamburger, 1963), balance assembly lines (Tonge, 1961), and perform numerous other tasks. More pertinent to the subject of this paper is the recent work of Ansoff and Brandenburg (1971). They have sketched out a flowchart for a heuristic model which matches a business firm's design criteria against the consequences of alternative organizational forms.

The initial and current version of the model discussed here was constructed from the existing literature, primarily the ideas of J. D. Thompson (1967, pp. 57-61). His propositions are formulated well enough that they may be considered as rules for structuring an organization's technical core (essentially its production activities). They still remain vague enough that a certain amount of interpretation was necessary. Recall that Thompson speaks about three types of technological interdependencies: reciprocal (inputs of each of two units are outputs of the other), sequential (output of one unit is input of another), and pooled (units in question are subject only to some overall constraint). Application of his propositions leads to a hierarchy of reciprocally related activities based on the intensity of interdependence, a hierarchy of sequentially related units based on the same principle, and a segmentation of pooled activities on the basis of homogeniety.

Let us first inspect the broad outlines of the model. It has been programmed in LISP, a list processing language. LISP's capabilities make it especially appropriate for the manipulation of lists of symbols into other lists of symbols. The model's informational inputs are a list of symbols representing the positions at an organization's workflow level plus lists of certain attribute values for each position. So far the

model has three attributes and their values associated with each position. These include (1) the other positions with which interdependencies exist and (2) the types of interdependence (reciprocal, sequential, pooled). Also included is (3) the intensity of interdependence (high, medium, low) for reciprocal and sequential activities, or three internally homogeneous groupings for pooled activities. The model's output is a list of the workflow positions, along with internally generated administrative positions, arranged in hierarchical order. This predicted configuration can be compared to the actual one in order to judge the appropriateness of the model. The administrative rules which transform the input list into the output list reflect one general organizing heuristic: structure the technical core from the bottom up by forming a hierarchical level from positions with the most intense level of interdependence remaining. Implicit in this rule is the assumption that intensity diminishes from reciprocal to sequential to pooled activities.

In order to examine the model in more detail it will be helpful to refer to the flowchart in Figure 1. The first step consists of forming from the input data the list of workflow positions (P list) and the attribute lists. In step 2 the model is set to handle reciprocal interdependence (ITD=3) of the highest intensity (ITN=3).[1] Step 3 involves using the P list to form a C list containing those positions with the current ITD and ITN values. If the C list turns out to be empty (step 4)

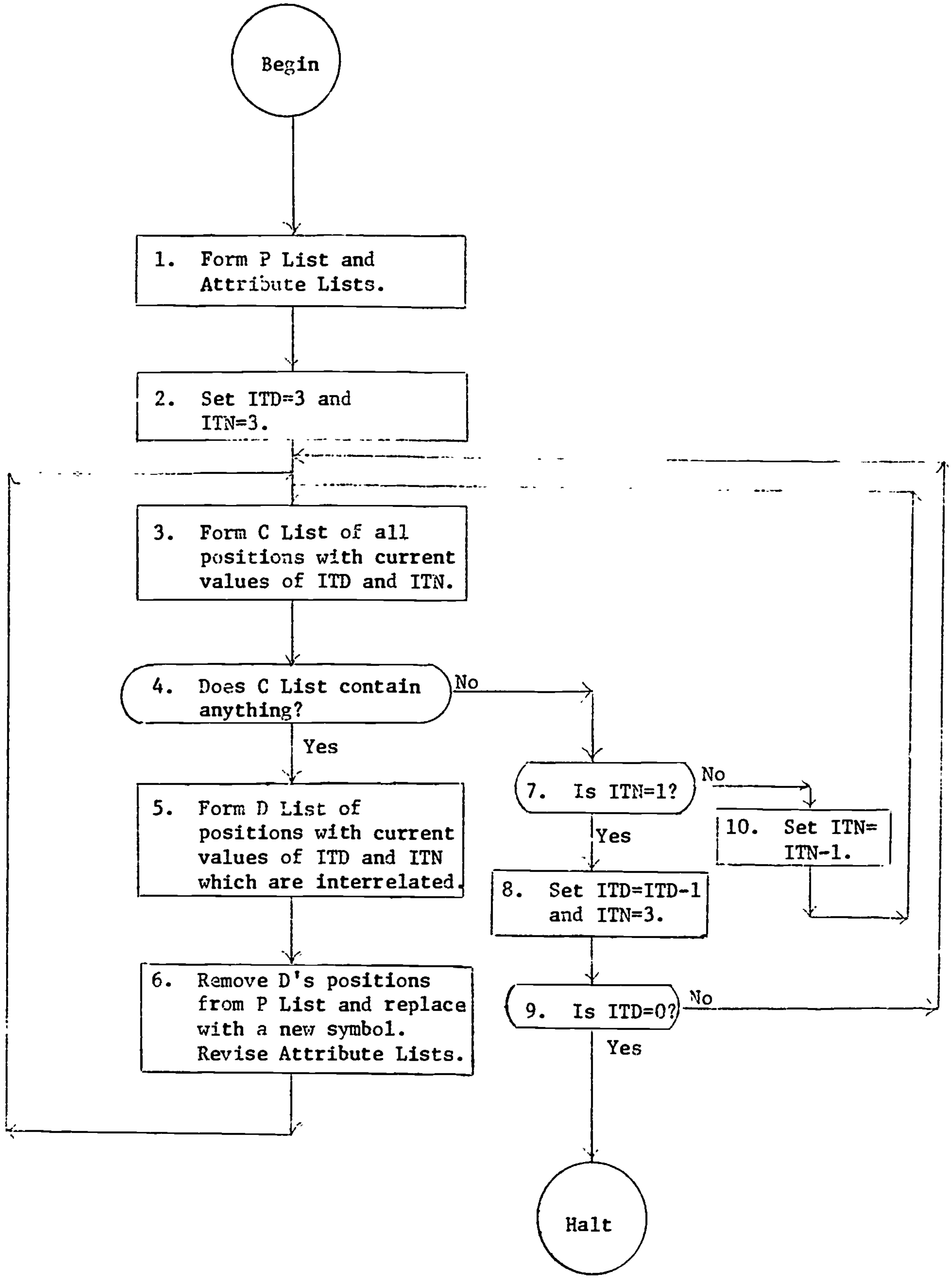

Fig. 1 Flowchart of Current Version of the Model

the model is set to handle the next most intense interdependence in steps 8 through 11. If it is not empty it is used in step 5 to formulate the D list. This contains positions with the current ITD and ITN values which are also interrelated with each other. The components of the D list meet the model's requirements for a work group. Hence, in step 6 an internally generated symbol, which can be interpreted as representing the position of group administrator, is assigned. The P list is revised by substituting the new symbol for the symbols of the group's components. An attribute list is created for the new group utilizing information in the attribute lists of the group's components. Finally, the attribute lists of P list members interrelated with components of the group at less intense levels than the current are altered to reflect interdependence with the group as a whole. The model now recycles to step 3. There may be other positions with the current ITD and ITN values interrelated with each other but not with any of those positions just grouped together. A new C list is formed and the entire process is repeated.

TESTING THE MODEL

The extent to which the model embodies Thompson's ideas was tested using his bomber wing example (1967, pp. 61-64). Once again, a certain amount of interpretation was necessary in order to operationalize his verbal statements. The informational inputs are depicted in Figure 2. There are three air crews of ten men each. All members of each crew are reciprocally related with high intensity with each other $(\overset{\leftarrow}{\underset{\rightarrow}{3}})$. Each crew is sequentially related at a high intensity $(\overset{3}{\rightarrow})$ with a different maintenance team. The team is used as the basic unit since no information is supplied

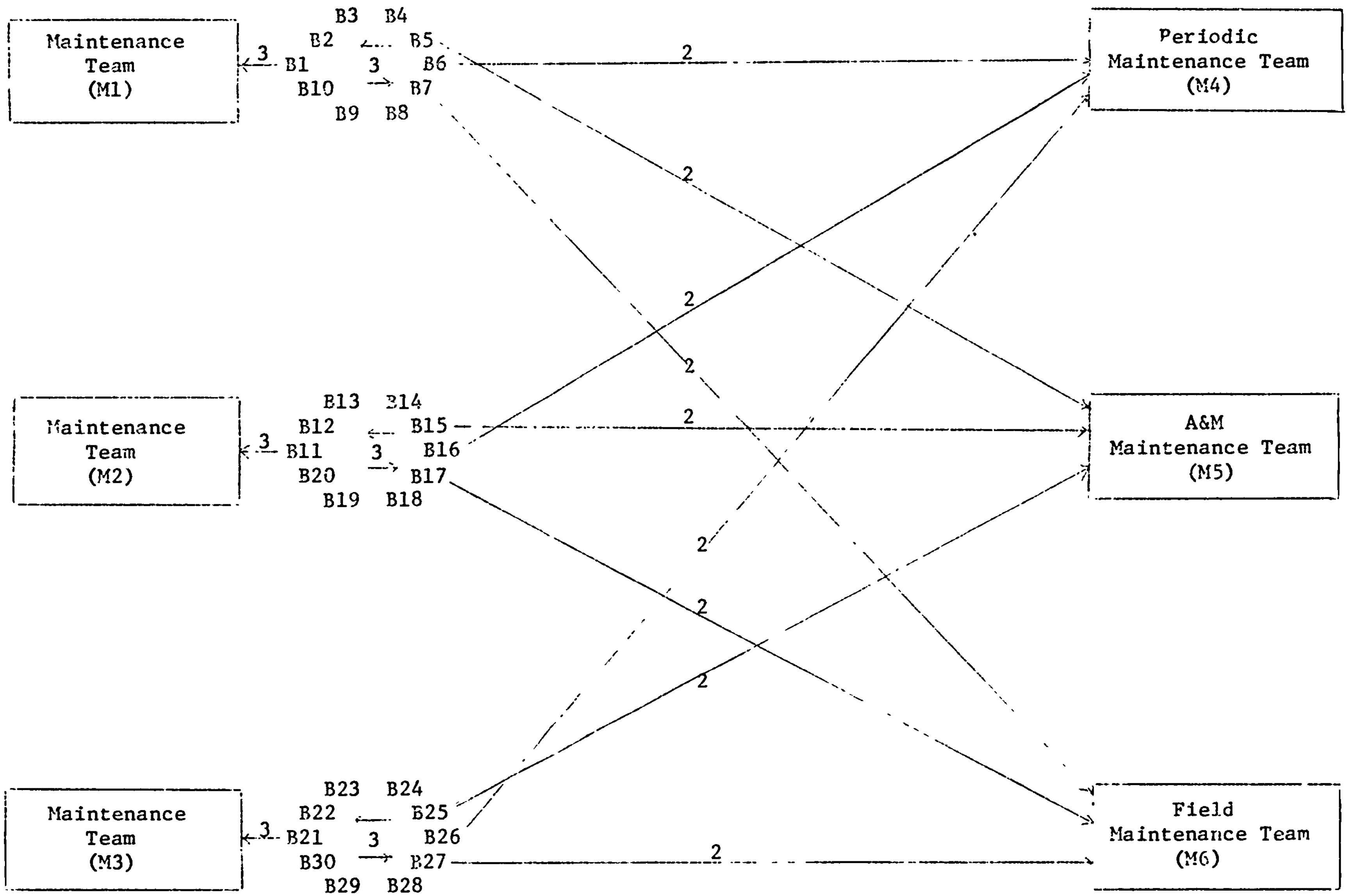

Fig. 2 Input for Bomber Wing Example

about its component positions.[2] Finally, the air crews are sequentially interdependent at medium intensity $\binom{2}{+}$ with three periodic maintenance teams.

A detailed account of the steps taken by the model to organize the components of the bomber wing is given in the Appendix. Figure 3 compares the actual configuration given by Thompson with that predicted by the model. The only discrepancy is that the model does not group the three periodic maintenance teams into a unit. This does not seem to be very crucial, especially in view of Thompson's observation (1967, p. 63) that the unit, "lacked a name but nevertheless was recognized by all concerned as headed by a director of material and his assistants." The discrepancy does tell us that there may be certain conditions under which pooled interdependence will be handled prior to sequential. It thus offers a clue that should be investigated further when it is time to refine the model's heuristics.

The test indicates that the initial version of the model is plausible. Further testing will be against data collected directly from organizations. It is planned to concentrate at least initially on industrial firms of the large batch or mass production type in order to insure that structure and technology will be salient characteristics. One method of testing is to formulate the model's important assumptions as hypotheses which can then be subjected to validation using standard statistical techniques. This would be appropriate for the key assumption that interdependence between units decreases as we move up the hierarchy. Once more, the iterative method by which heuristic models due to their complexity are typically validated will be used extensively. The current version of the model is

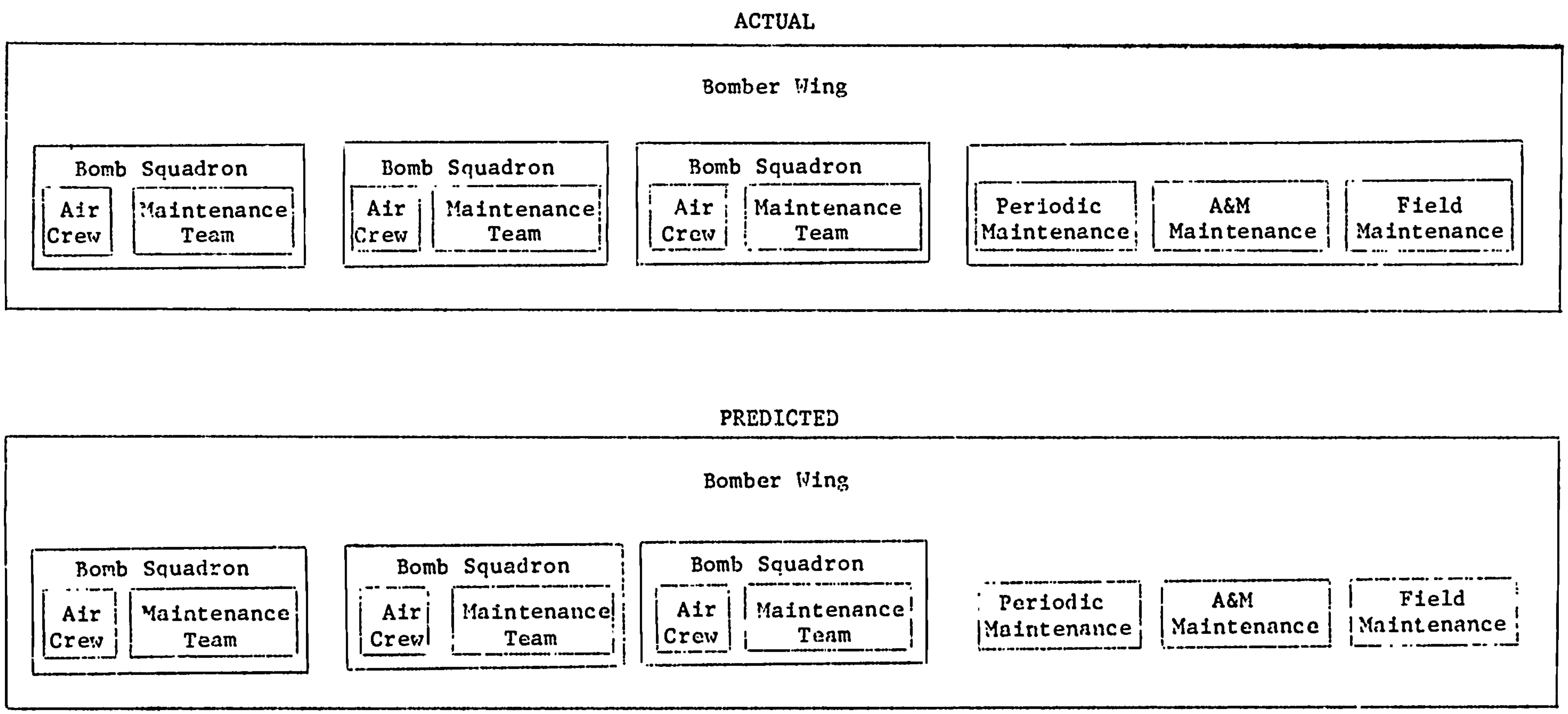

Fig. 3 Actual and Predicted Structural Configurations

tested against a small number of organizations. Comparison of predicted and actual configurations reveals which particular heuristics need revision. Once revisions are made the cycle is repeated until it appears that major changes are no longer needed. After a few cycles it is conceivable, although not necessary, that the model will bear little resemblance to the initial version.

Since further testing will involve originating methods for operationalizing concepts and collecting data it seems advisable to begin on a pilot scale. Data is currently being gathered in a small manufacturing firm. We are investigating such questions as how to determine the actual structural configuration without relying solely on organization charts, the nature and intensity of interdependencies, and the units in the technical core.

CONCLUSIONS

The significance of this research lies in its exploring the feasibility of a new way of rigorously analyzing the structural aspects of organizations. It combines the virtues of both comparative analysis and the constituent approach in that it allows in-depth analysis of the linkages among organizational components while at the same time providing a formal model for empirical testing. Constructing a model forces the researcher to find inconsistencies in his thinking and areas where thinking is not concrete enough. Analyzing the deviations between actual structures and the model's predictions will allow the refinement of theory in a systematic fashion. The model can also be used as a vehicle for determining which factors have the greatest influence on structure. This can be done by noting the effects

on predicted configurations of changes in various inputs. It may also be possible to explore the utility of the model for organizational design. For example, changes in technology can be simulated by altering the model's inputs and the resulting compatible structure determined.

These advantages do not imply this research is free of limitations. One model may not be adequate; a different one may be needed in different contexts. Data collection will be time consuming because of the detailed information needed from each organization. There may be no goodness of fit measure to determine statistically when a predicted and actual configuration are incompatible. Configuration is the only aspect of structure upon which the model focuses. The degree of formalization of rules, concentration of authority, supervisory style and other dimensions are not explicitly handled. A final set of limitations is more apparent than real. It is true that the model as it initially stands considers hierarchy as the only integrating mechanism, does not allow for staff positions, and has no maximum limit on the span of control. The type of control system, behavioral factors, size and other variables which may affect the technical core's structure are not included. However, as long as all these factors enter into or affect structure in a systematic manner they can eventually be incorporated into the model if needed.

Currently the model is essentially a formalization of Thompson's propositions and is being used as a means of testing them. The primary aim of this research, however, is to use his ideas as a starting point from which to develop a theory of organizational structure. The theory will consist of the model's rules refined using the iterative testing procedure. Consequently, the intent is to gradually expand the focus

of the research until the entire organization and variables which are not technological in nature are considered. In the long run, models of this type could be built for widely varying kinds of institutions. It is not contemplated that I will do all this myself. Rather it is hoped that my initial efforts will stimulate others to also utilize the new approach. Then models in varying contexts can be compared to discover widely applicable heuristics. The result should be a better theoretical understanding of technological and other influences on structure and consequently sounder policy recommendations for redesigning organizations.

APPENDIX

In order to illustrate the workings of the model the steps taken to predict the structural configuration of Thompson's bomber wing are listed below. The left column indicates the step number from Figure 1, the middle column explains what the step does, and the right column shows the result of applying the step.

1.	FORM P LIST	(M6 M5 M4 M3 M2 M1 B30 B29 B28 B27 B26 B25 B24 B23 B22 B21 B20 B19 B18 B17 B16 B15 B14 B13 B12 B11 B10 B9 B8 B7 B6 B5 B4 B3 B2 B1)
2.	SET FOR HIGH, RECIPROCAL	ITD=3, ITN=3
3.	FORM C LIST	(B30 B29 B28 B27 B26 B25 B24 B23 B22 B21 B20 B19 B18 B17 B16 B15 B14 B13 B12 B11 B10 B9 B8 B7 B6 B5 B4 B3 B2 B1)
4.	DOES IT CONTAIN ANYTHING?	YES
5.	FORM D LIST[1]	(Q1 B10 B9 B8 B7 B6 B5 B4 B3 B2 B1)
6.	REVISE P LIST	(Q1 M6 M5 M4 M3 M2 M1 B30 B29 B28 B27 B26 B25 B24 B23 B22 B21 B20 B19 B18 B17 B16 B15 B14 B13 B12 B11)
3.	FORM C LIST	(B30 B29 B28 B27 B26 B25 B24 B23 B22 B21 B20 B19 B18 B17 B16 B15 B14 B13 B12 B11)

4.	DOES IT CONTAIN ANYTHING?	YES
5.	FORM D LIST	(Q2 B20 B19 B18 B17 B16 B15 B14 B13 B12 B11)
6.	REVISE P LIST	(Q2 Q1 M6 M5 M4 M3 M2 M1 B30 B29 B28 B27 B26 B25 B24 B23 B22 B21)
3.	FORM C LIST	(B30 B29 B28 B27 B26 B25 B24 B23 B22 B21)
4.	DOES IT CONTAIN ANYTHING?	YES
5.	FORM D LIST	(Q3 B30 B29 B28 B27 B26 B25 B24 B23 B22 B21)
6.	REVISE P LIST	(Q3 Q2 Q1 M6 M5 M4 M3 M2 M1)
3.	FORM C LIST	( )
4.	DOES IT CONTAIN ANYTHING?	NO
7.	IS INTENSITY LOW?	NO
10.	SET INTENSITY TO MEDIUM	ITN=2
3.	FORM C LIST	( )
4.	DOES IT CONTAIN ANYTHING?	NO
7.	IS INTENSITY LOW?	NO
10.	SET INTENSITY TO LOW	ITN=1

3.	FORM C LIST	( )
4.	DOES IT CONTAIN ANYTHING?	NO
7.	IS INTENSITY LOW?	YES
8.	SET FOR HIGH, SEQUENTIAL	ITD=2, ITN=3
9.	IS ITD=0?	NO
3.	FORM C LIST	(Q3 Q2 Q1 M3 M2 M1)
4.	DOES IT CONTAIN ANYTHING?	YES
5.	FORM D LIST	(Q4 Q1 M1)
6.	REVISE P LIST	(Q4 Q3 Q2 M6 M5 M4 M3 M2)
3.	FORM C LIST	(Q3 Q2 M3 M2)
4.	DOES IT CONTAIN ANYTHING?	YES
5.	FORM D LIST	(Q5 Q2 M2)
6.	REVISE P LIST	(Q5 Q4 Q3 M6 M5 M4 M3 M2)
3.	FORM C LIST	(Q3 M3)
4.	DOES IT CONTAIN ANYTHING?	YES
5.	FORM D LIST	(Q6 Q3 M3)
6.	REVISE P LIST	(Q6 Q5 Q4 M6 M5 M4)
3.	FORM C LIST	( )

4.	DOES IT CONTAIN ANYTHING?	NO
7.	IS INTENSITY LOW?	NO
10.	SET INTENSITY TO MEDIUM	ITN=2
3.	FORM C LIST	(Q6 Q5 Q4 M6 M5 M4)
4.	DOES IT CONTAIN ANYTHING?	YES
5.	FORM D LIST	(Q7 Q6 Q5 Q4 M6 M5 M4)
6.	REVISE P LIST	(Q7)

The succeeding steps involve a cycle among steps 3, 4, 7, 8, 9 and 10 until ITD=0 at which point the model halts.

FOOTNOTES

TEXT

[1] We have ITD=3 (reciprocal), =2 (sequential), =1 (pooled). When ITD=2,3 ITN=3 (high), =2 (medium), =1 (low). When ITD=1 the three numerical values of ITN represent three different internally homogeneous groupings.

[2] Interdependence between crew and team is manifested by a relationship involving a particular position (e.g., B1). Any or all of the crew positions could have been used without affecting the results of the model.

APPENDIX

[1] The left most symbol in the list is for the internally generated administrator and all others represent the component positions.

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